MATERIAL MOTIONS AND EJECTION VELOCITIES FOR IMPACTS IN POROUS TARGETS.

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Many asteroids and some satellites have remarkably low densities, in some cases as low as ~ 1 gm/cm^3, as demonstrated by spacecraft and telescopic observations [1]. The interiors of these objects may be comprised of as much as 70% void space [1]. In contrast, much of our empirical knowledge of impact cratering is based on experiments in materials with only moderate porosity, about 35% or less. Highly porous materials might respond much differently to impacts because of the energy expended in irreversible compaction of pore spaces and the scattering of the shock when it encounters large voids [2, 3].

Experiments conducted over the past few years have demonstrated an interesting characteristic of crater formation in highly porous materials. Small craters are formed with the usual substantial deposit of ejecta surrounding the crater. On the other hand, large impacts form craters without ejecta blankets [4, 5]. This unusual behavior was explained as follows. Whereas craters in moderately porous materials, like sand, form by shearing and excavation, impacts into highly porous materials form mostly by crushing and permanent compaction. Ejection velocities should be relatively low in porous materials because of the rapid decay of the peak stress as the shock proceeds from the impact point. The slow ejecta would not be able to escape from the crater. Even with this "fall back" of ejecta, a crater is still formed because of the volume created by compaction. This explanation was based solely on observations of the final crater and ejecta deposit. The purpose of this report is to summarize recent experimental observations of the dynamics of crater growth in porous materials. These experiments largely support the explanation given above, but show some interesting differences as well.

The present experiments were performed using a "quarter-space" fixture [6] consisting of an open-top aluminum box 24 cm x 24 cm x 42 cm. One of the 24x42 cm walls is a 5.1cm-thick transparent Plexiglas window. The projectile strikes the target at the target/window interface. A Hycam film camera (~11,000 frames/s) looks into the window to record the growth of the transient crater and the motions of colored tracer particles.   An objective of these experiments is to determine how the kinematics of crater growth and cratering flow field depend on target porosity.

All of the experiments used cylindrical polyethylene projectiles with a nominal diameter and height = 1.22 cm, density = 0.93 gm/cm^3, and velocity = 2.0 km/s. The impacts occurred normal to the target surface in a chamber pumped down to a pressure of ~ 10 mm Hg. The targets were made from quartz sand (F75, median grain size ~ 200 μ) and perlite, a porous crushable silicate material, mixed with a small amount of water and then oven-dried. This allowed the sand and perlite to be mixed evenly without the use of any binders. Hence, the targets had very little cohesive strength. Three proportions of sand and perlite were used to obtain materials with bulk porosities of 67%, 55% and 35% (pure sand) and bulk densities of 0.87, 1.19 and 1.75 gm/cm^3 respectively.

Figure 1 shows the launch velocities of the top row of tracer particles, whose initial positions were at the target surface. Remarkably, the ejection velocity of these particles is quite insensitive to target porosity. This may be due to the fact that high pressures never develop near the target surface, so the effects of compaction may be minimal there. This is consistent with the fact that the near-surface perlite particles appear to be launched intact even though they are easily crushed. Analysis is underway to determine how the velocities of the sub-surface particles depend on porosity.

Figure 1 is not a complete picture of how the launch velocity depends on porosity because the target density is also varied. From this data set alone, one cannot sort out the effects of the two variables (because only a single impactor density was used).

Some insight can be gained by plotting the results using point-source scaling relationships [7, 8], which account for variations in the ratio of target density to projectile density. As shown in Figure 2. the ejection velocities for the sand target (35% porosity) lie about a factor of 2 above those for the porous materials. Note also, that the results for sand are in reasonable agreement with previous velocity measurements for sand [6, 9]. These results suggest that when differences in target density are accounted for, ejection velocities decrease as target porosity increases. Additional experiments are underway to address this issue in detail.

Observation of the motions of the tracer particles show a marked dependence of the cratering flow field on target porosity. Figure 3 compares the paths of tracer particles for the sand target to those for the target with 67% porosity. For the sand crater, the paths of all particles in the top three rows turn upward toward the surface, consistent with the notion that craters in sand form by shearing of material along the wall of the expanding crater.   Even the particles that end up beneath the crater show evidence of upward curvature. On the other hand, the flow lines in the porous target

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tend to be directed radially from the impact point. Only the uppermost tracer particles are ejected. The target with 55% porosity (Figure 4) shows an intermediate behavior with some material being ejected, but much of it being driven downward. Hence, while the crater in sand formed mostly by excavation, the craters in the porous targets formed mostly by compaction as the material is driven downward into, rather than along, the transient crater bowl.

References: [1] Britt, D.T., Yeomans, D. Housen, K. and Consolmagno, G. (2002). To appear in ICARUS. **[2]** Holsapple, K.A., Giblin, I., Housen, K., Nakamura, A. and Ryan E. (2002) To appear in ICARUS. **[3]** Asphaug, E, Ryan, E.V. and Zuber, M.R. (2002). To appear in ICARUS. **[4]** Housen K.R., Holsapple, K.A. and Voss M.E. (1999) *Nature*, 402, 155-157. **[5]** Housen K.R. and Holsapple K.A. (2003) To appear in ICARUS. [6] Piekutowski A.J. (1980) Proc. LPSC 11th Vol 3, 2129-2144. **[7]** Housen, K.R., Schmidt, R.M. and Holsapple K.A. (1983) *J. Geophys. Res.*, 88, 2485-2499. **[8]** Holsapple, K.A. and Schmidt R.M. (1987) *J. Geophys. Res.* 92, 6350-6376. **[9]** Cintala M.J., Berthoud L. and Horz F. (1999) *Meteoritcs & Planet. Sci.* 34 605-623.
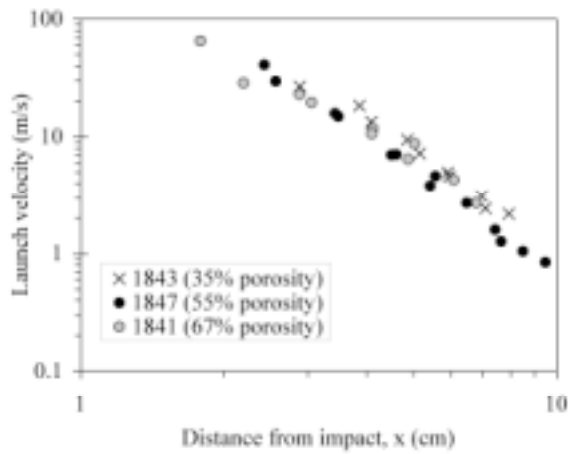

Figure 1. Ejection velocity vs launch position for tracers placed at the target surface.
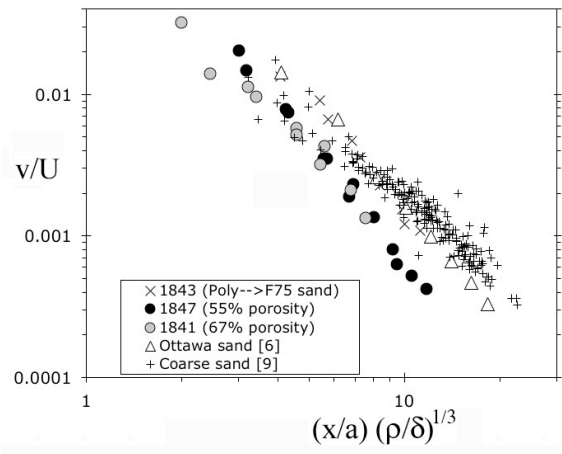

Figure 2. Ejection velocity plotted in a form consistent with point-source scaling laws, where v=ejection velocity, U = impact velocity, x= launch position, a=impactor radius, ρ=target density, δ=impactor density.
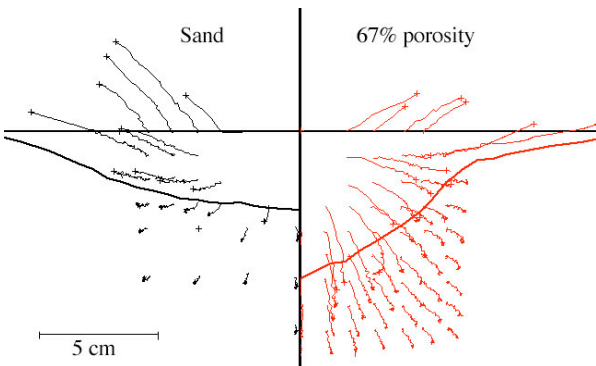

Figure 3. Comparison of paths followed by tracer particles for impact into sand (left side) and into a target with 67% porosity (right side). The plus sign at the end of a trajectory indicates the tracer particle disappeared in the next time step of the film record.
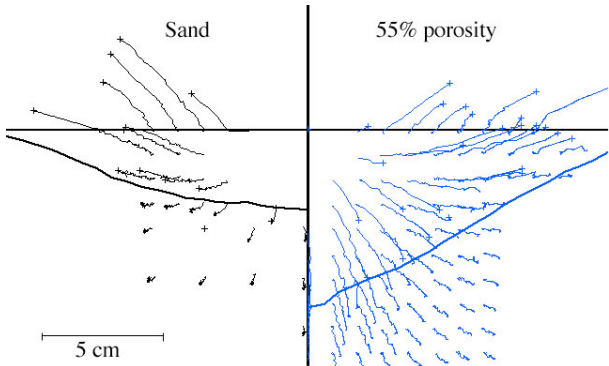

Figure 4. The particle motions for the target with 55% porosity are intermediate between the sand crater and the material with 67% porosity. While most of the material is driven downward, there is more evidence here of the trajectories turning upward to eject material from the crater.